THE STARDUST SOLAR ARRAY

Steve Gasner, Khaled Sharmit, Paul Stella*, Calvin Craig, Susan Mumaw
Lockheed Martin Space Systems Company
1111 Lockheed Martin Way
Sunnyvale, California 94089

* Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California, 91109

The Stardust Program, part of NASA's Discovery Missions was launched on February 7, 1999. It's seven-year mission is to gather interstellar dust and material from the comet Wild-2 and return the material to earth in January 2006. In order to accomplish this mission, the satellite will orbit the sun a total of three times, traversing distances from a little under 1 AU to 2.7 AU. On April 18th 2002 , the Stardust spacecraft reached its furthest distance and broke the record for being the farthest spacecraft from the sun powered by solar energy. The Stardust solar panels were built with standard off the shelf 10 Ohm-cm high efficiency silicon solar cells. These solar cells are relatively inexpensive and have shown excellent characteristics under LILT conditions. In order to accommodate the varying temperature and intensity conditions on the electrical power subsystem, an electronic switch box was designed to reconfigure the string length and number of strings depending on the mission phase. This box allowed the use of an inexpensive direct energy transfer system for the electrical power system architecture. The solar panels and electrical power system have met all requirements. Telemetry data from the solar panels at 2.7 AU are in excellent agreement with flight predictions.

Subject Number 3, III-V, Space Cells and Systems
Preferred presentation mode – Oral

THE STARDUST SOLAR ARRAY

Steve Gasner, Khaled Sharmit, Paul Stella*, Calvin Craig, Susan Mumaw
Lockheed Martin Space Systems Company
1111 Lockheed Martin Way
Sunnyvale, California 94089

* Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California, 91109

Steve Gasner, Lockheed Martin Missiles & Space, 1111 Lockheed Martin Way, Sunnyvale, CA 94089 Org L230, Bldg. 149, Phone (408) 742-7538, FAX (408)742-7701, Email steve.gasner@lmco.com
Khaled Sharmit, Lockheed Martin Astronautics, 12257 South Wadsworth Blvd., MS:S8350, Littleton, CO 80125, Phone (303) 971-2222, Fax (303)971-4306, Email: khaled.s.sharmit@lmco.com
Paul Stella, Jet Propulsion Laboratory, MS 303-308, 4800 Oak Grove Drive, Pasadena, CA 91109, Phone (818) 354-6308, FAX (818) 393-4272, Email paul.m.stella@jpl.nasa.gov
Calvin Craig, Lockheed Martin Astronautics, 12257 South Wadsworth Blvd., MS:S8350, Littleton, CO 80125, Phone (303) 971-7709, Fax (303)971-4306, Email calvin.l.craig@lmco.com
Susan Mumaw, Lockheed Martin Astronautics, 12257 South Wadsworth Blvd., MS:S8700, Littleton, CO 80125, Phone (303)971-5990, Fax (303)977-7515, Email susan.j.mumaw@lmco.com

On February 7, 1999 the Stardust spacecraft was launched. The Stardust Program is part of NASA's Discovery Missions, which are low-cost solar system exploration missions with highly focused science goals. The Lockheed Martin Space Systems Company built the Stardust Spacecraft. The Jet Propulsion Laboratory manages the Program. Stardust's seven-year mission is to gather interstellar dust and material from the comet Wild-2 and return the material to earth. In order to intersect the comet in January 2004, the spacecraft must make three loops around the sun for an encounter with Wild-2 at a distance of 1.86 AU. The spacecraft will then orbit the sun one more time before dropping off a probe with the samples to earth in January 2006. On April 18th 2002, the Stardust spacecraft reached its furthest distance (aphelion) from the sun at 2.72 AU setting the record for being the farthest satellite from the sun powered by solar energy.

This paper presents the design rationale, design, test program, and flight data for the Stardust Solar panels. The Stardust solar panels have unique requirements compared to standard solar panels. At near earth the array operates at 70°C at 1 sun solar intensity. At 2.72 AU the array operates at –61°C at an intensity of 0.135 suns. The solar cells used must operate at 1 AM0 and under low intensity low temperature (LILT) conditions. Standard silicon solar cells under LILT conditions have shown poor performance in the past. Given the criteria of the Discovery Missions, the preceding conflicting requirements had to also be met with a low cost, low risk solution. A trade study was performed on using single junction 18.5% Gallium Arsenide (GaAs) solar cells versus standard 16.7% high efficiency silicon (HES) solar cells. Results from LILT radiation testing on off the shelf HES silicon solar cells showed good performance under LILT and radiation testing. The passivation layers in the HES solar cell protect them from parasitic contact/junction losses and provide for high shunt resistance. The results of the trade actually showed the HES solar cells to have better performance under LILT than the GaAs solar cells. This is due to the higher temperature coefficient for the HES solar cell over the GaAs solar cell. Because of the better performance and significantly lower cost than GaAs solar cells, off-the-shelf Sharp HES 10 Ohm-cm solar cells were selected for the mission.

In order to meet the conflicting requirement for the solar array to operate at 1 AM0, moderate temperatures and LILT conditions, an electrical power system (EPS) trade was performed. Two direct energy transfer (DET) EPS solar arrays were compared with a peak power tracking (PPT) EPS. One of the DET EPS used a large solar array. The other DET EPS used a small solar array combined with an electric box that can reconfigure the string length and number of strings depending on the operation mode. In order to use a DET EPS architecture, solar cell string sizes near earth would have to be long in order to support voltage requirements and at deep space, more strings would be needed to satisfy current requirements. The Stardust vehicle did not have the real estate for a large solar array. The trade showed that a small solar array with an electronic switch box was the most compact, lowest weight, and least expensive compared to a peak power tracking system.

The Stardust solar array consists of two wings. Each wing has 3 solar panels, a forward panel, a midboard panel, and an aft panel. Two sizes of solar cells were used, 4x6 cm^2 and a 2x2 cm^2. The 2x2 cm^2 solar cells were used to trickle charge the batteries. As stated before, the solar cells were standard off-the-shelf Sharp 10 Ohm-cm HES solar cells with an average efficiency of 16.7%. After solar cell selection, a detailed characterization of the solar cell under LILT and radiation conditions for all mission phases was performed at the Jet Propulsion Laboratory (JPL). The solar panels were designed and fabricated using standard proven practices used at Lockheed Martin. A qualification solar panel and qualification solar panel wing was fabricated. The solar panel went through an electrical performance acceptance test, a qualification acoustic and thermal vacuum thermal cycle test along with solar array wing deployment testing. The flight solar array wings and panels also went through the same test but at acceptance levels. In addition, the flight solar panels went through a thermal vacuum bake out.

On each midboard solar panel were mounted two strings of three solar cells in series. The purpose of these strings is to monitor short circuit current and open circuit voltage. In addition, telemetry allows the monitoring of current from all circuits, solar array usage, battery voltage, solar cell temperature and solar array off pointing angle. From this information, solar array output can be monitored during the mission and compared to predictions. For comparison to spacecraft (S/C) telemetry, solar array predictions used the solar array models employed in the design of the array. Additional inputs were obtained from the solar panel acceptance test data, the solar panel temperature and angle telemetry, battery voltage telemetry, and adjusted GOES satellite solar flare data to account for radiation degradation. The results of a comparison of telemetry versus prediction at 2.7 AU (aphelion for this mission) is shown below.

	PREDICT	ACTUAL	ERROR
Isc Sensor	133.3 mA	136.1 mA	2.1%
Voc Sensor	2201 mV	2,221 mV	0.9%
Array Current Output	171.6 W	172.6 W	0.6%

As can be seen, the telemetry is in excellent agreement with predicts.